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THE NUTRITIONAL SIGNIFICANCE OF THE CARBOHYDRATES

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THE NUTRITIONAL SIGNIFICANCE OF THE CARBOHYDRATES

By W. A. KREHL, Ph.D.*

INTRODUCTION

Despite our increasing desire for thick, juicy steaks and other foods of high protein content, we continue to derive about 50 per cent of our total caloric intake from carbohydrate (1).

Carbohydrate furnishes the bulk of our food energy, and it also serves as an important part of many body components such as nucleic acids, galactolipids of brain tissue, and the connective tissue matrix.

In addition, man derives considerable pleasure from food items sweetened with sugar; well known is the psychological value of a box of candy for mom or sweetheart, or a lollipop to sooth Junior's ruffled feelings.

The newer concepts of a dynamic biochemistry and intermediary metabolism have evolved largely because of the detailed explorations into the enzymatic breakdown of the carbohydrate molecules by the yeast cell and animal tissues.

Inasmuch as foods that have a high carbohydrate content are less expensive than the protein-rich foods, the percentage of carbohydrate in the diet increases as the economic ladder is descended. This becomes of considerable concern if the foods selected are highly refined grains or sugars which carry little or none of the protective vitamins, minerals, or essential amino acids.

Carbohydrates are compounds representing hydrates of carbon and contain hydrogen and oxygen in the ratio of 2:1. The formation of carbohydrates in nature represents perhaps the most important reaction essential to continued life — the photosynthetic reaction. This chemical reaction is written

$$CO_2 + H_2O + \text{sunlight} \xrightarrow{\text{chlorophyll}} (CH_2O) + O_2,$$

where the (CH_2O) represents a carbohydrate corresponding to one gram atom of carbon (2). The green plant is the factory in which photosynthesis is carried out and carbohydrate produced and stored.

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Classification of Carbohydrates

Monosaccharides

(a) ***Hexoses***
Glucose
Fructose
Galactose
Mannose

(b) ***Pentoses***
Ribose
Xylose
Arabinose

Sugar Alcohols
Sorbitol
Mannitol

Disaccharides
Sucrose
Lactose
Maltose

Polysaccharides
Cellulose and Hemicellulose
Inulin
Mannosans
Pentosans
Starch and Dextrins
Glycogen
Galactogens

Mucopolysaccharides

Hyaluronic acid (N-acetyl-D-glucosamine; D-glucuronic acid.)

Chondroitin Sulfuric Acid (N-acetyl-D-galactosamine; D-glucuronic acid; sulfate.)

Alpha-heparin — D-glucosamine; D-glucuronic acid; sulfate.

Beta-heparin — N-acetyl-D-galactosamine; D-glucuronic acid; sulfate.

Keratosulfate — N-acetyl-D-glucosamine; galactose; sulfate.

Although this classification is not complete, it will serve for the purposes of the discussion to follow:

Body Composition and Turnover of Carbohydrate

Carbohydrate makes up about three-fourths of the plant world upon which animal life depends primarily for its food supply. In spite of ingesting a substantial amount of carbohydrate every day, the animal body contains a remarkably small amount of this substance. Protein is the principle structural element of an animal, fat its chief source of reserve calories, yet carbohydrate is its principal active fuel. This reflects the tremendous chemical activity incident to the metabolism of carbohydrate.

It has been estimated (3) that the total carbohydrate content of an average well nourished 70 Kg. man is quite small, amounting to about 370 gm., derived as follows: muscle glycogen (0.70 per cent) — 245 gm; liver glycogen (6 per cent) — 108 gm; blood and extracellular fluid sugar (0.08 per cent) — 17 gm. If there were not a continual supply of carbohy-

drate, the above amount would be enough to supply the man's calorie needs for only about 13 hours.

The mammalian organism cannot function without a constant supply of carbohydrate. Any reduction of the blood glucose below a critical level will lead to disaster, especially for the delicate tissues represented in the central nervous system which can use only glucose as a source of energy.

Should glucose therefore be considered an essential nutrient? No — not in the sense that it must be present in the diet as such. Two general mechanisms are drawn upon to assure a consistently adequate blood glucose level. The first is the ability of the body to convert the various digestible hexose-yielding carbohydrates in the diet to glucose. The second is the homeostatic mechanisms which are called into play whenever the blood glucose level starts to fall. If the glycogen reserve is adequate, it is first broken down to yield glucose, but in the face of minimal glycogen stores and no intake of dietary carbohydrate, the proteins of the body are then called upon to serve as a source of blood glucose via gluconeogenesis, i.e., the synthesis of new glucose. This is a stress phenomenon, under the control of the adrenal corticoids. It has enabled man to overcome hypoglycemia, coma, and death during moderate periods of starvation, and has permitted him to expand his horizons beyond the immediate limits of his food supply and in circumstances of emergency.

Just as body protein can serve as a source of carbohydrate, so can dietary protein. It has been shown (4) that approximately 58 per cent of dietary protein may be converted into glucose. We recognize, therefore, glucogenic amino acids. This is obviously an uneconomical process because of the much greater cost of protein compared with carbohydrate. It is a factor, however, which must be given special consideration during periods of growth, such as infancy and childhood, and during the rehabilitation of body proteins subsequent to burns, surgery or other trauma involving severe protein losses. An adequate level of carbohydrate must be supplied under such circumstances since it is evident that the amino acids of the ingested protein cannot serve as a source of energy or carbohydrate and still be incorporated into the structure of new tissue proteins.

Excess ingested carbohydrate is not stored as such, but is transformed into fat and deposited in the fat depots of the animal. On the other hand, fatty acids do not seem to contribute significantly to the carbohydrate content of the body. Glycerol does serve as a precursor of glucose or glycogen.

Digestion, Absorption, and Utilization of Carbohydrates

The carbohydrates of the diet become available to the animal after they are finally broken down by enzyme action to the monosaccharide state. How-

ever, as will be discussed later, there is evidence for the direct absorption of the disaccharide lactose. Since the crude fiber content of the average human diet is low (5 to 20 gm. per day) the digestibility of available carbohydrate is high. Atwater considered satisfactory a figure of 97% for the digestibility coefficient of carbohydrate in "the average American diet" (5). Considering the fact that all carbohydrates do not have the same calorie value as measured in the bomb calorimeter, and using the above figure for digestibility, Atwater arrived at the figure of 4 Cal. per gm. for the "physiological fuel value of carbohydrate." This figure can vary depending on the carbohydrate employed in the diet and the amount of roughage present. One should therefore be cautious in applying this figure to "book analyses" of diets to ascertain their true caloric value.

Despite the fact that many substances, including sugars, have been reported to be absorbed from the stomach, completely adequate methods for studying this have not been found. Experimental work with rats by most investigators has not provided evidence for glucose absorption from the stomach (6).

The small intestine is the principal site for absorption of the digestion products of carbohydrates, as well as proteins and fats. The work of Cori (7) showed that considerable differences exist in the absorption rates of the different monosaccharides. If one arbitrarily assigns an absorption rate for glucose as 100, the relative-absorption rates of the other sugars are: galactose 110, fructose 43, sorbose 30, mannose 19, xylose 15, and arabinose 9. On the other hand, when these sugars are introduced into the peritoneal cavity, they are absorbed at the same rate; further, when two sugars in solution are introduced into the intestine and absorbed simultaneously, the absorption rate for each is reduced. The rate of absorption following a dose of glucose decreases with time. Carbohydrate absorbed per unit time is increased as the concentration of the carbohydrate solution is increased (8).

Hormonal activities influence carbohydrate absorption. The absorption rate is decreased by hypophysectomy and thyroidectomy, while insulin and thyroid hormone act to increase the rate of absorption of carbohydrate.

It is interesting that the character of the diet, as well as fasting conditions, affects the absorption rate of sugars. Either high-fat diets or fasting conditions diminish the absorption rate and also the ability of the animal to oxidize carbohydrate.

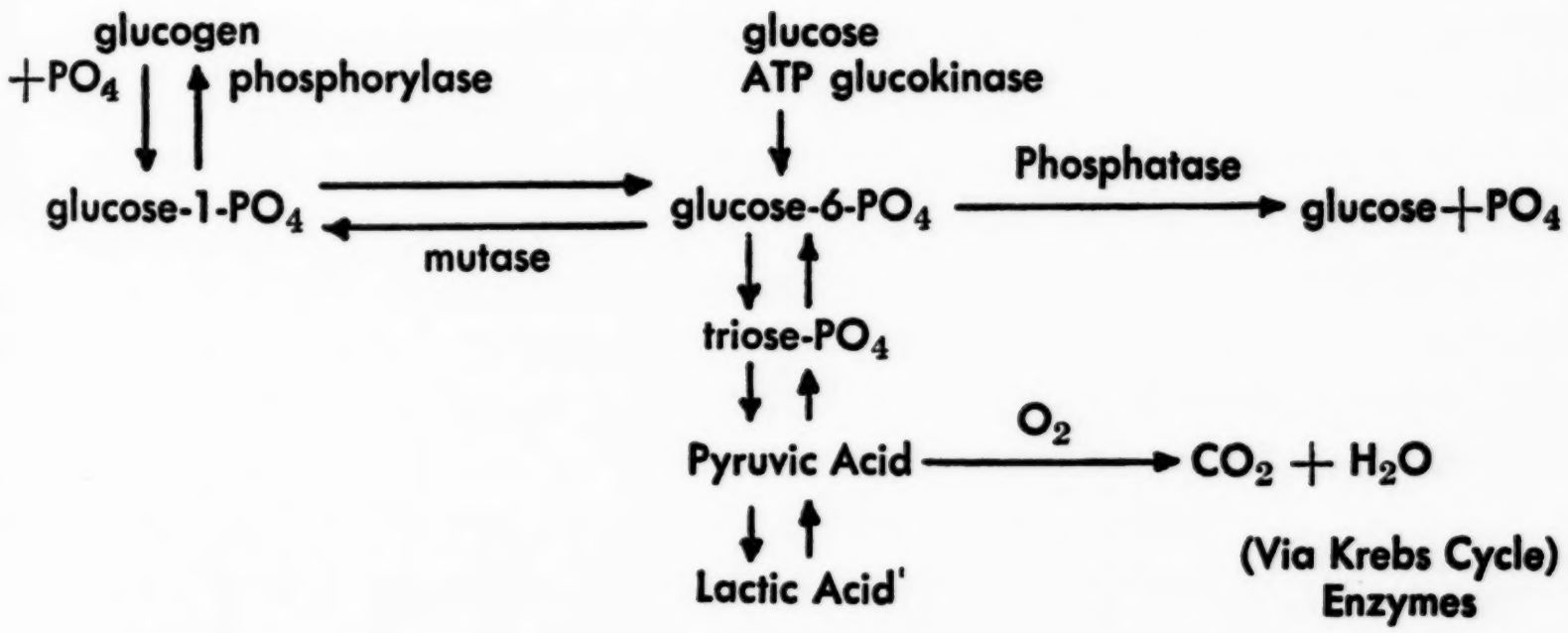
Absorption from the intestine may be accounted for by two mechanisms: (a) a nonspecific absorption by diffusion involving a concentration gradient between the sugar in the cells of the mucous membrane of the intestinal tract and the sugar in the intestinal lumen, and (b) an acceleration of the diffusion process by phosphorylation of the sugar within the cell. The second

may be demonstrated by the increase in organic phosphate in the intestinal mucosa during sugar absorption (9) and because poisons, such as phloridzin (10) and iodoacetic acid, which block phosphorylation reactions, reduce the absorption of hexose sugars.

Quastel has reported an interesting experiment in which he studied the absorption of sugars from isolated surviving intestine (11). His findings agree essentially with those of Cori, except that Quastel observed a much lower rate of absorption for sorbose. Quastel also found that intestinal absorption of fructose results in its transformation into glucose during transfer through the intestinal wall. "Any absorption of fructose as such is due to a diffusion process in the isolated guinea pig intestine, the rate of fructose diffusion being no greater than that of sorbose."

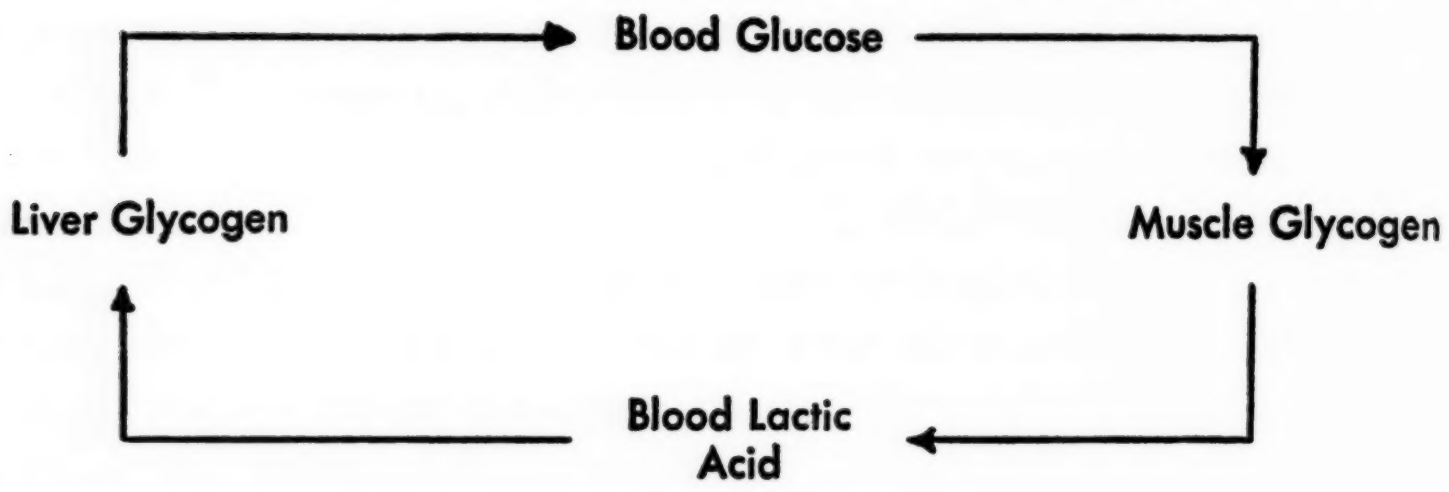
The key carbohydrate of the body — glucose — is the ultimate end for the hexoses, fructose, galactose, and mannose. The absorbed pentoses appear to be disposed of in the peripheral tissues or are excreted in the urine.

It is beyond the scope of this article to discuss the reactions by which glucose is metabolized to yield CO_2, water and energy, but the following will outline the basic steps involved:



The Meyerhof-Embden-Parnas scheme of phosphorylative glycolysis represents the main pathway of carbohydrate metabolism in the animal which leads to the formation of 2 molecules of lactic acid from 1 molecule of glucose (12). In the presence of oxygen, lactate does not accumulate and pyruvate is converted to CO_2 and water via the Krebs Cycle (13).

During muscular exercise the lactic acid formed by the working muscle diffuses into the circulation and reaches the liver where it is converted to glycogen. This glycogen serves then as a source of blood glucose from which muscle glycogen may again be formed. This is known as the Cori cycle (14).



Specific Carbohydrates in Nutrition

Only those carbohydrates will be discussed which seem to have special significance either as the result of new work or because of the economic and practical importance of the carbohydrate involved.

Syrups containing glucose and dextrins are made by the mild acid hydrolysis of starch, followed by neutralizing, decolorizing, and concentrating the liquid to about 80 per cent solids. Much of this so-called "flat" syrup is used in candy making. Cane syrup is added to flat syrup to improve flavor, and the product, called "corn" syrup, has a popular table use and is employed in infant milk formulas. Crystalline glucose, as crystals of hydrated glucose, is much used as a source of carbohydrate in experimental animal nutrition. Glucose is only about 75 per cent as sweet as the common sugar sucrose. The comparative sweetness of some of the more common sugars, assigning sucrose a value of 100, is as follows: fructose 173, glucose 74, maltose 33, galactose 32, and lactose 16.

Glycogen is not an important dietary source of carbohydrate, since it is present in such a limited amount in animal tissues. The liver can, with a diet high in carbohydrate, store glycogen to the extent of 10-15 per cent. This is not the usual case, however. Glycogen is a branched chain, high molecular weight polysaccharide, a polymer of glucose. Glycogen is not fermented by yeast, but is readily hydrolyzed by amylase. Diastase (plant amylase), ptyalin (salivary amylase), and amylopsin (pancreatic juice amylase) convert glycogen into maltose. An interesting glycogen storage disease is Von Gierke's disease in which excessive amounts of glycogen are stored in the liver or muscles, including the heart muscle. This unusual form of glycogen is not broken down by the usual degradative enzymes and ultimately deranges the physiology of the organism and causes death.

Starch

By all odds, starch is the most important dietary carbohydrate, since it contributes more calories to the average human diet than any other single

substance. Starch, like glycogen, is a high molecular weight polymer of glucose and is present in nature in two separable forms: (a) amylose, a long unbranched chain, and (b) amylopectin, which is a branched chain polysaccharide. Amylases are the enzymes which catalyze the hydrolysis of starch (also glycogen). Since the amylases can attack only the α-1-4 linkage between the glucose units of starch, amylose is completely broken down into maltose units, while the breakdown of amylopectin stops when branch side chains in the starch polymer are reached. This results in the production of limit dextrins which are composed mostly of glucose tri- and tetrasaccharides. Dextrins have a wide commercial usage and have also been used extensively in experimental diets in nutrition experiments.

Cellulose (The Roughage Factor)

Cellulose comprises at least 50 per cent of all the carbon in vegetation (15) and is the most abundant organic compound in the world. Cellulose is an unbranched chain of D-glucose units which resembles amylose except that it has a much higher molecular weight and the glucose units are joined together in β-1-4 linkage and are hence resistant to the action of amylase.

Cellulose serves as a source of available carbohydrate for ruminants because of the action of bacterial enzymes present in the rumen. In man and other non-ruminant vertebrates, cellulose is non-digestible and contributes to the bulk of the diet, and may assist in the elimination of food residues. As stated before, bulk in the diet may alter the digestibility of other carbohydrates and other food substances. Cowgill and Anderson (16) in a study on the rate of laxation in human beings ingesting controlled diets, concluded that a minimum of approximately 100 mg. of fiber per kilogram of body weight should be taken daily in order to assure proper evacuation. Cathartics of crude fiber (cellulose) should not be employed in circumstances of intestinal ulceration, stenosis, or disabling adhesions (17). Synthetic hydrophilic colloids derived from cellulose, such as methylcellulose and sodium carboxymethylcellulose, are relatively new agents employed as bulk cathartics.

Sucrose and Sugar Products

The use of sugar in the diet dates back to a very early period in man's history, and its importance in the diet of modern man is indicated by the per capita consumption in the U. S. of nearly a hundred pounds of sugar per year for the last 40 years (18).

The relative efficiencies of various agricultural products can be compared by tabulating the areas of land necessary for producing one million calories in one year. The million calorie figure is derived from the fact that an adult, moderately active man requires food equivalent to about one million calories per year. The two commercial sugar producing plants, beet and cane, provide by far the largest food yield when this is expressed as calories per acre of land. Stated another way, sugar provides calories at the lowest cost compared with other common foodstuffs.

Refined sugar, one of the purest organic chemicals available in huge quantities, does not, however, provide vitamins, proteins, amino acids, lipids, and minerals. The "naked purity" or uncovered calories of pure sugar naturally make it a threat to good nutrition if protective foods are not incorporated in the diet. Extravagant claims have been made by food cultists and faddists concerning the vitamin and mineral value of certain raw, crude, and "integral" sugars. An extensive study of the vitamin and mineral composition of raw sugars, soft sugars, turbinado sugars, "integral" sugar, and even dried cane juice indicates that such materials do contain these nutrients, but in such small quantities as to be completely impractical as nutritional sources (19).

Blackstrap molasses does contain more vitamins and minerals than the sugars mentioned above. But even here if one should be so misguided as to consume a pound of blackstrap molasses per day, the reward would be about 64 per cent of the recommended niacin allowance and 34 per cent and 54 per cent of the thiamine and riboflavin allowances, respectively (20). While molasses has important nutritional attributes in the feeding of cattle for reasons other than its vitamin content, its role in human nutrition as a possible source of vitamins is insignificant.

Shaw (21) has recently reviewed the nutritional relationships of carbohydrates to tooth decay and draws several conclusions: (a) microorganisms are required to cause tooth destruction, (b) the absence of normal saliva results in an increase in tooth decay, (c) the form in which the various carbohydrates are fed is important. With solutions of sucrose there is little tendency for carious lesions to develop, while consumption of sucrose in granular form increases caries development, (d) a genetic factor may be important in the susceptibility to caries development, and (e) the importance of rapid oral clearance of sugar is one of the strong determining factors on the extent of tooth decay.

Fructose

Fructose, or levulose, is present in the free state generally in association with glucose and sucrose and is particularly abundant in ripe fruits and in

honey. Free fructose is also found in fetal blood, in amniotic fluid and in seminal plasma. Fructose is the hexose present in the polysaccharide inulin, which is present in substantial amounts in the Jerusalem artichoke. The commercial synthesis of fructose has also been achieved. Fructose has considerable industrial value because it is the sweetest of all sugars and because it does not crystallize readily. This property is employed in sirups to prevent the crystallization of unhydrolyzed sucrose.

Great interest in the past few years has been focused on fructose because of its value when given intravenously in the treatment of diabetics (22).

Several investigators have demonstrated the superior utilization of fructose in diabetes and the failure of insulin to affect the rate of fructose utilization (23, 24). Smith et al (25) have also reported that patients with hepatitis and cirrhosis given intravenous tolerance tests of fructose and glucose utilize fructose normally, while glucose utilization is impaired.

It is presumed that the diabetic can utilize intravenously administered fructose without the intervention of insulin because fructose is phosphorylated via a fructokinase which does not require the action of insulin as does glucokinase, the enzyme mediating the phosphorylation of glucose. Fructose can, therefore, enter the glycolytic metabolic scheme while glucose cannot unless insulin is present.

Fructose given orally exerts little or no beneficial effect for the diabetic unless insulin is present, since, as stated earlier, fructose is converted to glucose during transfer across the intestinal mucosa.

Parenteral Administration of Carbohydrates

In the parenteral administration of carbohydrates, it should be pointed out that to avoid glucosuria, the rate of administration of glucose should not be greater than 0.5 to 0.75 gm. per kilogram of body weight per hour (26). The utilization rate of fructose by parenteral administration is greater than that of glucose (27). The problem of sparing tissue proteins becomes great when the sole source of calories is from 5 per cent intravenous glucose, because of liquid-volume limitations. It is, therefore, considered advisable (28) to employ 10 per cent solutions of glucose or fructose to supply added calories and minimize gluconeogenesis.

Certain carbohydrates have also been used as plasma extenders for the management of shock. Intravenously administered glycogen is broken down slowly to dextrin and glucose and hence remains in the blood for a fairly long time (29). Dextran, a bacterial polysaccharide, is also being used as a plasma extender with some success (30), although much additional work must be done in evaluating this product.

Lactose

The milk of mammals is the only known source of lactose and is present in amounts ranging from 2.0 to 8.5 per cent.

Percentage Composition of Milk From Different Species (31)

Type	Protein %	Fat %	Carbohydrate %	Ash %
Cow's milk	3.3	3.8	4.8	0.71
Goat's milk	3.4	4.1	4.7	0.77
Human milk	1.2	3.8	7.0	0.21

Lactose is not very soluble and not very sweet. The lactose of commerce is α-lactose hydrate; anhydrous β-lactose, a more soluble and sweeter form of the sugar, can be made by crystallizing lactose at a temperature above 95° C. In milk or after standing in solution, α and β-lactose form equilibrium mixtures.

In the intestine, lactose is hydrolized by the enzyme lactase to its constituent monosaccharides, glucose and galactose. Early studies by Folin and Berglund (31a) showed that lactose can be absorbed directly, since it appeared in the urine after an oral dose of the sugar. The lack of a tissue or blood lactase makes lactose unavailable when in the metabolic pool of nutrients. Lactose is slowly absorbed and a portion of it continues through the small intestine to reach the colon. Here intestinal microorganisms metabolize it to yield among other things lactic acid. Lactose is effective in reducing intestinal pH and establishing a Gram-positive flora. Lactose forms a suitable medium for the "bifidus" flora essential to the production of the "bifidus" factor (32).

As indicated before, galactose is converted by the liver to glucose and hence metabolized; in addition galactose has a role in the formation of certain mucopolysaccharides and the cerebrosides of nerve tissue. Wick and Drury (33) note that galactose can enter extrahepatic cells and that this can be accelerated by insulin, yet "the intracellular enzyme system has little if any capacity to oxidize galactose."

Lactose in infant feeding has had a varied and interesting history. Finkelstein in 1906 (34) set a pattern against the addition of lactose to infant formulas on the grounds that it or its metabolic acid products caused inflammation of the alimentary tract and that the inflamed mucosa permitted absorption of undesirable materials. This seems most puzzling in view of the high lactose content of human breast milk on which babies thrive.

Since 1928 a number of laboratories have studied the effect of added lactose to cow's milk formulas for infants. Gerstley (35, 36) reported that as much as 12 gm. of lactose could be added per 100 cc of cow's milk without producing diarrhea in infants. In addition, their stools had a weight, acidity, and lactic and volatile acid content similar to those of breast fed infants.

Jarvis (37) fed mixtures of cow's milk, water and lactose to over 1000 infants without finding any evidence of intolerance. He stated — "The tissues of these children seemed more firm than that of the average infant receiving vegetable sugar and resembled the breast fed infant." Jarvis concludes therefore that lactose should be the sugar of choice for normal infants.

When an excess of lactose is given or when the dietary level of lactose is increased too quickly, diarrhea may result. The level and kind of fat in the diet may be important in lactose or galactose utilization. Boutwell et al (38) showed that lactose gave a poor growth performance in rats fed corn oil, but with butterfat, growth approached that obtained with other sugars. The difference in value between corn oil and butterfat became greater as the lactose of the diet increased.

Too high a level of lactose in the diet of a rat will produce cataract (39), although strain differences appreciably modify this effect (40). Infants that have a congenital inability to metabolize galactose develop severe galactosemia, galactosuria, weight loss, vomiting, cataract and mental retardation, probably as the result of brain damage due to essential hypoglycemia (low blood glucose). It is essential in such infants to alter the formula to a non-lactose diet. Fortunately, this is a rare condition.

One of the most important functions of lactose may be in relation to calcium metabolism. If one removes the parathyroids of dogs fed a non-lactose diet (41) they soon develop severe tetany which can be promptly abolished by feeding 15% lactose or galactose (42) in relatively small amounts. Aside from the partial effect of lactose increasing calcium absorption because of lowered intestinal pH, this observation remains unexplained.

Very recent and interesting work has been done by Fournier (43) on the relation of lactose to calcium metabolism. Diets that contain either lactose, D and L xylose, and D and L arabinose doubled the coefficient of utilization of dietary calcium as compared with a starch containing diet. He considers lactose, galactose, xylose and arabinose structural carbohydrates. Fournier offers the suggestion that lactose participates in the function of the bone cell, and that the lactose molecule has a specific function relative to calcium metabolism. If lactose as such functions in the structure and composition of bone, the relatively small amount that is absorbed unchanged must be involved.

Mucopolysaccharides and Mucoproteins

The mucopolysaccharides are complex chemicals which seem to contain two or more compounds, one of which is an amino sugar. Hyaluronic acid, present in synovial fluid, vitreous humor, umbilical cord, skin, and bone is no doubt the best known of the mucopolysaccharides. It is composed of N-acetyl-D-glucosamine and D-glucuronic acid. The mucopolysaccharides usually exist in loose association with a protein. In muco-proteins on the other hand the polysaccharide is much more tightly bound to protein. They are predominately protein. The preponderance of protein in the chicken egg is a mucoprotein (ovomucoid), and at least four gonadotrophic hormones are mucoproteins.

Much interest has been stimulated in the mucopolysaccharide-protein complexes. Many clinical studies have shown (44) "that the protein-bound carbohydrate content of serum is significantly elevated in neoplastic diseases, rheumatic fever, rheumatoid arthritis, lupus erythematosus disseminatus, pregnancy, diabetes mellitus associated with vascular complication, tuberculosis, myocardial infarction, obstructive liver disease, irradiation and aging."

Heparin, which occurs in highest concentration in mast cells (45) has come in for great experimental and clinical interest, because heparin on intravenous injection reduces the turbidity of lipemic plasma. This is due to the activation by heparin of lipoprotein lipase, an enzyme in plasma which catalyzes the hydrolysis of the neutral fat chylomicrons (46). In addition, of course, heparin exerts its well known anticoagulant effect.

The anti-lipemic action of heparin and similar substances has evoked considerable interest as a possible means of treating atherosclerosis associated with hypercholesteremia and elevated chylomicron blood levels.

Sugar Alcohols

Sorbitol and mannitol are hexahydric alcohols and are found in nature as sweet ingredients of many edible fruits and berries. They are about as sweet as glucose. Both sorbitol and mannitol are absorbed more slowly from the intestine than the common sugars or glycerine. Sorbitol is completely though slowly absorbed, is glycogenic and has a caloric value equivalent to sugar (i.e.) 4 Cal. per gm. Mannitol, on the other hand, is less completely absorbed and has a caloric value of about 2 Cal. per gm. (47). The slow rate of absorption of these sugar alcohols tends to temper the acute demand for insulin and hence encourages their use in diabetic foods as sweetening agents.

These substances merit consideration because of their use in foods: sorbitol is used as a humectant conditioning agent in various types of foods,

and mannitol which is relatively non-hydroscopic is often mixed with hygroscopic food products, particularly food powders, to reduce agglomeration and to keep the food product in free running condition.

Summary

Carbohydrate makes up the bulk of man's energy supply. It need not be considered a dietary essential since the metabolic machinery can synthesize carbohydrate from protein. This of course is an expensive procedure. The small but vital stores of carbohydrate serve as a ready source of energy for emergency purposes.

Glucose is the key metabolic carbohydrate. It can be stored to a limited degree in the form of glycogen; oxidized to carbon dioxide and water with the liberation of energy; or converted into fat which serves as a reserve source of energy. In addition glucose is the essential energy-yielding metabolite for nervous tissue. All of the other hexose yielding carbohydrates are ultimately converted to glucose via the processes of digestion, absorption or metabolism.

In addition, certain of the carbohydrates, such as lactose and fructose, have interesting special functions under particular circumstances. Sweetness and palatability is given to food by many of the sugars, and complex sugars form important substances in the structure of the body.

A diet which supplies a level of protein to cover the needs of growth and repair of body tissues; a fat intake which provides the essential fatty acids and a solvent for the fat soluble vitamins; an adequate intake of vitamins and minerals; and enough carbohydrate to supply the remainder of the required calories seems both a practical and economical diet. One would expect the individual to flourish on such a regimen without becoming obese — the goal of good nutrition.

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5228

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